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To eradicate or not to eradicate? Recommendations on *Prosopis juliflora* management in Afar, Ethiopia, from an interdisciplinary perspective

John Ilukor*, Simone Rettberg, Anna Treydte and Regina Birner

Abstract

As one of the most invasive species of arid and semi-arid areas of East Africa, *Prosopis juliflora* has become a major threat to livelihoods of the Afar pastoral people and to the fragile ecosystems they live in. This paper comprises results from a multidisciplinary study on the spread of *P. juliflora* as an invasive species in the Ethiopian Afar Region and provides suggestions on its management and control. The study investigated spread of *P. juliflora*, ecological aspects (shifts in vegetation biomass and soil properties) and socio-economic aspects (livelihood impacts, management activities and potential) of *P. juliflora* invasion. Ecological methods included conducting destructive harvesting on vegetation; soil analyses and a soil seed bank assessment as well as using allometric equations to estimate the biomass and carbon contents of *P. juliflora*. Socio-economic data was collected based a survey of 490 pastoral households including 213 from Amibara, 177 from Gewane and 100 from Awash Fentale. Stated and revealed preference methods (RPM) were used because impacts of *P. juliflora* are both tangible and intangible. The study found that wetlands (flood plains in the Awash Basin) are highly susceptible to Prosopis invasion relative to drylands. Clearing invaded land and continuously using it for crop farming would reduce the invasion. The study also found that the available nitrogen, phosphorus and organic carbon in the soil were high in highly invaded areas compared to less or non-invaded sites. However, the basal cover of native herbaceous vegetation and native tree diversity were found to be much reduced under high *P. juliflora*-invaded areas. Results from economic analyses also reveal that the benefits of the *P. juliflora* invasion in the Afar region are higher than the costs. However, some aspects such as increased risk of erosion, the impact of *P. juliflora* on the water table and long-term ecological changes were not examined, thus making the total economic valuation incomplete. Nonetheless, the study has captured most aspects of *P. juliflora* invasion in the Afar region and concludes that sustainable management and control of *P. juliflora* in the Afar region may be a better solution than eradication.

Keywords: *Prosopis juliflora*, pastoralism, costs and benefits, invasive species

Background to the study and findings

The spread of invasive plant species within the arid and semiarid lowlands of Northeast Ethiopia is an increasing threat for pastoral livelihoods and ecosystems. One of the most invasive species is *Prosopis juliflora*, an evergreen, fast-growing tree or shrub, native to South and Central America (Mwangi and Swallow 2008). The Ethiopian National Biodiversity Strategy and Action Plan (MoARD 2005) considers it to be one of the top invasive species countrywide, next to Parthenium weed (*Parthenium hysterophorus*), water hyacinth (*Eichhornia crassipes*) and Lantana weed (*Lantana camara*). *P. juliflora* was first introduced to the Afar region by the Ethiopian government in the late 1970s and early 1980s to combat desertification, and by 2006, approximately 700,000 ha of land had been taken over by *P. juliflora*, out of which more than 70% is located in the Afar region (Admasu 2008; Ryan 2011).

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P. juliflora has been reported to offer significant ecosystem and livelihood services such as microclimate regulation, improvement of soil fertility, reclaiming saline and alkaline soils and income and livelihood diversification (Bhojvaid and Timmer 1998; Berhanu and Tesfaye 2006). This is particularly important for the arid lands of Afar, 50% of which is exposed soil, sand and rock (ANRS 2010). Along the Awash River flood plains, dense woodland and swamps have been reclaimed for irrigation (ANRS 2010). Kahi et al. (2009) found that soils under *P. juliflora* had higher organic carbon and total nitrogen than soils in the open areas. Although soils under Acacia spp. trees had higher organic carbon and total nitrogen than soils under *P. juliflora* (Kahi et al. 2009), Acacia spp. trees are not capable of surviving in the Afar region. *P. juliflora*'s high coppicing ability and deep roots enable them to survive in drylands where they provide a number of benefits including alternative energy sources (Ayanu et al. 2015). The pods from *P. juliflora* can also be a source of nutritious human food (Choge et al. 2007) as well as a nutritious, less costly feed ingredient for livestock (Sawal et al. 2004; Stein et al. 2005; Chaturvedi and Sahoo 2013). Both crushed and uncrushed *P. juliflora* pods can be fed to livestock (Berhanu and Tesfaye 2006) and in pastoral areas like Afar with acute shortage of fresh water, *P. juliflora* has been seen as an alternative source of feed because it tolerates adverse arid conditions (Mahgoub et al. 2005).

Recent studies by Ayanu et al. (2015) and Haregeweyn et al. (2013) have shown that the *P. juliflora* invasion rate is increasing rapidly, suppressing indigenous plants, while negatively affecting human health as well as livestock production. *P. juliflora* creates an environment conducive for mosquito breeding, limits access to watering points and grazing lands and offers cover for wild predatory animals such as lions (*Panthera leo*) (Pasiecznik et al. 2001; Mehari 2015). Attempts to access these areas have resulted in injuries to both animals and humans (Mwangi and Swallow 2008). Afar pastoralists who call it the "Devil Tree" and the "AIDS" to the animals want it to be eradicated. Policy-makers and development partners are faced with the dilemma of whether to completely eradicate *P. juliflora* or manage this species intensely. However, the measures that have been adopted in the Afar region have thus far not been able to manage and control this species' rapid spread and it appears that the negative impacts exceed the positive impacts, especially for pastoralists, the main inhabitants of Afar Region in Ethiopia.

Against this background, the German Ministry for Economic Cooperation and GIZ (Gesellschaft für Internationale Zusammenarbeit) decided to fund an interdisciplinary research study on "Woody Encroachment in the Afar Region, Ethiopia: Impact Assessment of *Prosopis* Invasion and Participative Management Approaches". In 2013 to 14, the study was implemented by Ethiopian-German research teams led by the University of Hohenheim (ecology, economy) and the University of Bonn (sociology, remote sensing) in association with the Mekelle University, Samara University and Ethiopian Environment and Forestry Research Institute. The project's objective was to assess the extent and impact of land degradation through *P. juliflora* in the Afar Region, and to estimate the costs and benefits of *P. juliflora* invasion. It was decided to focus on an empirical case study within one of the most heavily invaded areas in Afar, the Middle Awash Basin, the seasonally inundated floodplains of Gewane and of Amibara Woreda, where *P. juliflora* has spread rapidly over the last decades (Müller-Mahn and Rettberg 2012).

Results

The invasion and spread of *P. juliflora*

The quantitative assessment of *P. juliflora* spread within the Baadu area (Gewane Woreda) was based on a comparison of Cloud-free Landsat ETM (30-m resolution) and ASTER (15-m resolution) satellite images taken during the dry seasons (October–March) of 2000, 2005, 2010, and 2013. The results revealed that the rate of *P. juliflora* invasion over the past two decades is tremendously high, and within five years (2000 to 2005), the total area of wetlands invaded by *P. juliflora* increased from 3,600 to 8, 000 ha (i.e. from 8% to 18%). About 30% of the wetlands were invaded in 2010 - which is equivalent to a total area over 13,000 ha - and by the end of 2013, almost 40% of the wetlands in Baadu were invaded. This implies a 10% increment over a period of three years when compared with 2010 (Ayanu et al. 2015). The area of agricultural land invaded by *P. juliflora* was only 2 ha (<1%) even though it increased to 76 ha (4%) in the year 2005. By 2010, the total agricultural land invaded by *P. juliflora* had increased to 166 ha, but this amounted only to 2% of the total agricultural land. The reduction in the percentage of the invaded agricultural land is attributed to increased cultivated area compared with previous years, and overall increase in cultivated land could also be associated with *P. juliflora*, which is known to reclaim saline and alkaline soils, which might have made the soils available for cultivation. By the end of 2013, 4% (327 ha) of total area of agricultural land was invaded, and this is associated with the fact that investors abandoned their farmland, allowing *P. juliflora* to continue invading. Only 1% of the total drylands were invaded, and this is probably because animals do not graze in these areas and the soils have less moisture available to facilitate *P. juliflora* invasion (Treydte et al. 2014; Ayanu et al. 2015).

Ecological consequences of *P. juliflora* invasion

The acacia trees are not capable of surviving in Afar region and continue to provide fuel wood, charcoal and regulate the microclimate compared to prosopis. This

trend was similar for above and below ground biomass (see Figure 1).

The study also found that the available phosphorus and organic carbon in the soil were more than twice as high at highly and intermediate infested sites compared to low and non-infested sites. The nitrogen level and the moisture content in soils of highly infested areas were 23% and 11% to 13%, respectively. These levels are more than twice as high compared to those of low or non-infested areas. However, species diversity and richness of the woody vegetation in Gewane and Amibara were found to be very low (four to five species) even in areas without *P. juliflora*. In areas of high and medium *P. juliflora* invasion, the individuals or plants of other species were not available or recorded (see Table 1). Therefore, *P. juliflora* might reduce this diversity further. The basal cover of native herbaceous vegetation was found to be much reduced under high *P. juliflora* infestation.

However, the seed bank of soils under high *P. juliflora infestation* showed up to 14 different species available when grown in the greenhouse. Hence, there is potential for *P. juliflora*-infested soils that, once cleared, native vegetation might recolonize certain areas when resprouting of *P. juliflora* is suppressed simultaneously. Further, the number of *P. juliflora* seedlings was proportionally lower the higher the invasion rate, indicating that *P. juliflora* might suppress seedling growth through allelopathy and, hence, simulate self-thinning in areas of high presence.

With the loss of indigenous grasses and other plant species, the main fodder resource for grazers such as cattle, the number and productivity of animals has reduced substantially (Hamedu 2014). Yosef et al. (2013) using data from the Central Statistical Agency (CSA) of Ethiopia demonstrated that cattle and camel populations in the Amibara zone, which was the study area, declined at a rate of 36% and 20%, respectively, between 1997 and 2011 (see Table 2). Although the population of cattle in almost all other zones is declining, the percentage decline in Amibara is the highest compared to other zones (Yosef et al. 2013). In addition, Amibara is the only zone for which both camel and cattle number are declining and is also the zone which is highly invaded with *P. juliflora*.

Further, socio-economic impacts triggered by the invasion of *P. juliflora* comprised increased health risks due to higher exposure to predators and malaria, constrained access to water points and the emergence of new fatal animal diseases like "*Harmaku*", resulting from cytotoxins damaging the neurons of the intoxicated animals (Silva et al. 2007).

Nevertheless, *P. juliflora* is only one among several ecological problems. A ranking exercise within kebeles (A Kebele is the smallest administrative unit of Ethiopia similar to a ward) affected by *P. juliflora* revealed that Afar pastoralists perceived the diminishing water volume of the Awash River to be as problematic as the spread of *P. juliflora* or even worse (Hamedu 2014). Pasiecznik et al. (2001) contend that diminishing water volumes in rivers and water courses can be attributed to *P. juliflora* in areas invaded by Prosopis.

Most pastoralists within Baadu, previously known for their wealth due to large cattle herds, now live under conditions of chronic food insecurity (Rettberg 2010). The number of livestock is declining as households are selling off animals to buy food, and about 64% of the rural Afar households are consuming three or fewer food groups out of seven. In Ethiopia, Afar State has the households with the highest food expenditure and malnutrition as well as the lowest household cereal stock per capita (1 kg/person) at any given time (WFP 2009; CSA 2014). To cope with this food insecurity challenge, there has been a significant diversification of pastoralist

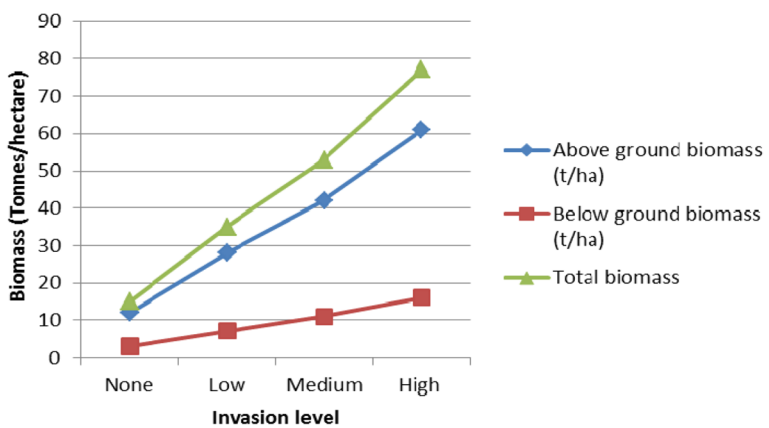

Figure 1 Above and below ground and total biomass of *Prosopis juliflora*-invaded sites across the different infestation categories as quantified through destructive harvesting

Table 1 Number of individuals per species for all woody plants recorded in the sample quadrants across the different *Prosopis juliflora* encroachment sites

Site	Species	High	Medium	Low	None
Amibara	*Acacia mellifera*	0	9	25	0
	Acacia senegal	0	0	0	928
	Dobera glabra	50	22	3	0
	Prosopis juliflora	4200	503	325	44
	Total	4250	534	353	972
Gewane	*Acacia mellifera*	0	0	0	13
	Acacia senegal	0	0	0	863
	Acacia seyal	0	0	25	0
	Acacia spp.	0	0	50	0
	Acacia tortilis	0	0	0	13
	Balanites aegyptiaca	0	0	13	0
	Dobera glabra	0	0	0	12
	Prosopis juliflora	3850	1775	1513	13
	Total	3850	1775	1600	913

livelihood strategies and engagement into non-pastoral economic activities. More and more pastoralists became sedentary within the last 20 years, performing different kinds of income-generating activities (wage labour, petty trading and sale of charcoal, firewood, grass mats, etc.) and small-scale irrigation agriculture (Rettberg 2010; Müller-Mahn and Rettberg 2012). Still, in most sedentary households, there are some boys and men who keep on moving with the remaining livestock and livestock is still the main food security asset.

Social and economic impacts of *P. juliflora*

Socio-economic data was collected from a survey of 490 pastoral households including 213 from Amibara, 177 from Gewane and 100 from Awash Fentale. The total economic value approach was used, and the valuation techniques applied are a combination of stated and revealed preference methods. Since the impacts of *P. juliflora* are both tangible and intangible, combining revealed and stated preference methods ensures that measurements of prices are drawn from the actual financial setting and welfare measurements are less prone to bias (Adamowicz et al. 1994, 1997; Earnhart 2001). In using stated preference techniques, households were asked to subjectively state the quantities and the value of environmental goods generated from Prosopis as shown below. In addition, pastoralists were asked to state the number of animals affected in the previous year, number of animals that died or were slaughtered, and to estimate the loss in weight as well as milk production that they attributed to the invasion of *P. juliflora*. This information was collected for each of six categories of livestock. For products that are traded in the market like milk and meat weights, the revealed preference method was used.

Only few Afar people value *P. juliflora* for its economic potential, considering it to be a "black gold" due to its monetary benefits through charcoal production and trade (Datona 2014). The results in Table 3 show that the main local use of Prosopis is for fuel wood, house construction and fencing houses and kraals. Very few households are engaged in selling fuel wood or charcoal burning. Also, very few households feed animals with pods and Prosopis leaves. This could explain why most households preferred complete eradication of the Prosopis. On average, 46% of the environmental income is associated with Prosopis. Only 18%, mainly young and educated Afar households, have been able to generate high profits through charcoal trade but with severe ecological consequences as indigenous trees are similarly (but illegally) cut, which is against the traditional law of the Afar (*maada*). This law is not respected anymore and the role of customary institutions in natural resource management is increasingly undermined, driven by the desire to diversify livelihoods and income sources in selling wood and charcoal (Datona 2014). There is also serious concern by some interviewed pastoralists that the few powerful people engaged in charcoal making are in favour of the spread of *P. juliflora* and, hence, are acting against encroachment control efforts. The risk of resource-based land conflicts within and among Afar clans and neighbouring ethnic groups in the *P. juliflora*-affected areas is increasing with the commodification of land through charcoal trade and agriculture (Hamedu 2014).

Results from economic analyses also reveal that the benefits of the *P. juliflora* invasion in the Afar region are higher than the costs. The total benefits in Ethiopian Birr amounted to about 4.4 billion (231 million USD), and the costs are estimated to be about 2.2 billion ETB (116 million USD). Results also show that if the current invasion level is not controlled, the net present value in

Table 2 The percentage change of cattle and camel in Afar State (Amibara and Mille), Somali region states (Shinile and Jijiga) and Borana zone

	Zones									
	Shinile		Jijiga		Amibara		Mille		Borena	
	Cattle	Camel	Cattle	Camel	Cattle	Camel	Cattle	Camel	Cattle	Camel
Percentage change	−14.6	16.5	−8.21	241	−36.2	−20	332	1203	−30.7	65.9

Source: Yosef et al. (2013)

Table 3 Main uses of *Prosopis juliflora* among Afar pastoral households

Environmental good	Harvests/year	Value/year (ETB)	Proportion due to Prosopis	% of HHs benefitting	Prosopis income/hh
Fuelwood, home consumption	119	2983	65	96	1939
Fuel wood for sale	153	5648	76	3	4292
Charcoal, home consumption (bags)	35	1712	86	18	1472
Charcoal for sale (bags)	1043	57,631	90	18	51,868
Poles for house construction	69	1664	54	52	899
Poles for house repair	26	210	68	47	143
Fencing (homes farm, kraal)	34	699	71	74	496
Farm implements	14	261	43	21	112
Household furniture	77	1636	17	4	278
Honey (litres)	48	5760	5	0.2	288
Wild fruits	65	530	4	3	21
Bush meat	12	2550	23	1	587
Medicinal use	49	1294	6	10	78
Leaves for livestock feed	175	3995	30	12	1199
Pods for livestock feed	136	3374	87	39	2935
Total		95,890	46		69,248

Source: Field Survey Data (January 2014 and December 2013): The harvest per year, value per year, proportion and the proportion of households earning a given income are generated from household survey data. Income due to Prosopis is computed from value per year based on proportion income associated to Prosopis

the next 30 years would be negative (37 trillion Birr) (Ilukor et al. 2014). However, the benefits and costs tend to vary between user groups such as mobile pastoralists, sedentary small-scale agro-pastoralists and large-scale farmers (Ayanu et al. 2015). In this study, we found that the benefits to sedentary small-scale agro-pastoralists who participate in wood and charcoal trade as well as to large-scale crop farmers are higher than the costs because land is cultivated and the wood is sold. The net present value for households who cut prosopis, sell its wood or charcoal is 516 ETB (27 USD) and for those who cultivate land and also sell wood or charcoal is 7985 ETB (420 USD) per year. Nevertheless, if the invasion is not controlled, the benefits to these user groups would be less than the costs in the near future. For this reason, pastoralists prefer complete eradication and are willing to contribute cash as well as labour to reach this goal relative to non-pastoral households (Tilahun et al. 2014). Our results also revealed that pastoralists are willing to pay 246 ETB (13 USD) and 38 labour days per household in a year to eradicate *P. juliflora*.

However, complete eradication might have significant impacts on the environment in the form of increased wind erosion, evapotranspiration, and sun radiation of opened areas (Haregeweyn et al. 2013). It would further reduce the ability of the Afar environment to sequester carbon as the estimated total C stock density derived from the *P. juliflora* invasion was about 40% higher (86 Mg C ha^{-1}) at high than at low (50 Mg C ha^{-1}) invasion categories ($p < 0.05$). Analyses of existing data about *P. juliflora* invasion generated from a study by Haregeweyn et al.(2013) and climate data acquired from the Amibara weather station reveal that the *P. juliflora* invasion has been useful in moderating climate variables and reducing expansion of desertification in the Afar region (Ilukor et al. 2014). Increased plant biomass above and below ground as well as higher organic matter content in soils through *P. juliflora* invasion can contribute to capturing CO_2 from the atmosphere, which is important for climate change mitigation (Hasen-Yusuf et al. 2013). It further can promote future Carbon trade efforts, which might provide an alternative income generation through payment for environmental services (PES). Moreover, as results from the ecological analyses reveal, the available phosphorus, nitrogen and carbon in the soil were found to be high in highly and intermediate *P. juliflora*-infested sites. Therefore, the soil properties in highly infested sites are suitable for plant growth or crop production once *P. juliflora* has been removed. Based on the soil seed bank study, the ecosystem might recover from *P. juliflora* infestation and native species might return. However, care has to be taken to prevent reinvasion of cleared sites as well as overgrazing as these factors threaten the competitive ability of the native plants in this semi-arid region.

Conclusion and recommendations

The results of the joint impact assessment presented above suggested that there is need for a participative, institutionalized, locally owned and government-led

management approach. Although this study tried to capture most aspects of the *P. juliflora* invasion in the Afar region, some aspects such as increased risk of erosion, the impact of *P. juliflora* on the water table and long-term ecological changes were not examined, making the total economic evaluation incomplete. However, based on our results, we provide the following recommendations for the sustainable management and control of *P. juliflora* in the Afar region.

Securing sustainable land reclamation

Results from the joint study suggest that total eradication of *P. juliflora* is impossible and not sustainable. The efforts and resources should be directed to clearing of *P. juliflora* in some selected areas with use of the wood for either charcoal or fuel wood and (b) immediate utilization of the cleared land for either pasture or crop farming with the objective of diversifying livelihood strategies. Implementation of this recommendation will require creating innovative ways of involving pastoralists in the mechanical clearing of *P. juliflora* by tapping into local knowledge, local institutions and providing land use rights of the cleared land as well as suitable tools for farming, especially generators for irrigation. Pastoral clans, institutions and locations should be mapped and documented. Each clan should be empowered to oversee the clearing of *P. juliflora*. The clans should be supported (financially and technically) and community rules should be revised to identify weaknesses and strengths in the management of *P. juliflora*. This support should essentially come from the government and even development partners. In addition, the same clans should also be offered secure rights to use the land for crop or forage production. Secure rights are important because currently the land belongs to the government, and households who were members of the cooperative noted that the land they cleared off *P. juliflora* was given away to the investor. This loss in 'ownership' certainly is one of disincentives to the management of *P. juliflora* in Afar.

Building multi-level institutions

For any management approach to become effective on the ground, there has to be a strong institutional structure with clear mandates and responsibilities. There should be a clear leadership in the control of *P. juliflora*. One organization at the federal level (preferably the Ministry of Agriculture) should be given the mandate as a lead organization to control the spread of *P. juliflora* (Chekol and Neumann 2014). Under the lead organization, further institutional structures or arrangements should be developed at all administrative levels at the regional level. All these governmental institutional structures will need transparent mandates and sufficient budgets for *P. juliflora* management. Local institutions at the regional and Woreda levels should be linked to customary institutional structures of natural resource management, e.g. through the establishment of joint boards or management committees.

Strengthening local institutions through participation and ownership

Both local- and national-level institutions and arrangements are needed to ensure sustainable management of *P. juliflora*. The local *P. juliflora* management institutions should be developed in line with the existing local institutions on pasture management and should be recognized by federal and regional governments. In Afar, there are customary leaders called *makabantu* that are involved in decision-making in matters related to clan grazing lands, relationships with other clans, neighbours and the state and the *fiimat abba* who enforce decisions made by the *makabantu* of individual clans and the clan leaders from the associated grazing lands ulooto) (see Oba 2012).

These existing local institutional structures should be activated and involved in the management of Prosopis, and this would require documenting existing 'clans' and an examination of their community rules before adapting them to the management of *P. juliflora*. In addition, this process would ensure that *P. juliflora* management institutions are developed participatively by involving communities and their leaders. Participatively developed institutions that are locally owned are the key to sustainable management and control of *P. juliflora* in the Afar region. They will ensure that pastoralist knowledge and views form the basis for control and management of *P. juliflora*, thus minimizing the tendency of forcing interventions on them. It also minimizes the "free rider problem", the tendency of some pastoralists or households not to participate in *P. juliflora* clearing or management but to benefit from the clearing by others. By providing social sanctions and incentives, pastoralists themselves who are strongly affected by *P. juliflora* invasion would be more actively involved in its management and control other than armed forces that have no incentives. Group-based sanctions or incentives such as clan sanctions or multi-clan sanctions would even be more effective (Reuben 2003).

Focusing on specific *P. juliflora*-invaded areas

Ecologically, some areas are better suited for *P. juliflora* eradication than others. Areas with high and dense *P. juliflora* cover might be too difficult and labour/finance consuming. These areas are likely to decline in *P. juliflora* in the future, anyway, due to self-thinning effects. In contrast, areas that have been invaded rather recently should be cleared selectively and intensely (including root removal). The latter areas are less densely populated with *P. juliflora* and might show the positive effects

of this species onto the soil nutrient and moisture properties as found in our study. These positive soil characteristics can be used for consecutive planting of native species or cropping fields.

The cleared areas should immediately be restocked with native woody and grassy vegetation to prevent new invasions as abandoned and unused areas are preferred colonization grounds for *P. juliflora*. Hence, restocked native woody and grassy vegetation or a cropping field, e.g. a dense maize field, will prevent *P. juliflora* from spreading.

Further, the remaining grazing areas should be managed such that no overgrazing effects arise as the latter will encourage *P. juliflora* invasions. The grass layer must be kept intact and should be interspersed with few native trees but *P. juliflora* growing into tree shape can also be allowed.

The spread of *P. juliflora* should be undermined by collecting pods regularly and crushing them before livestock can forage on these plant parts as livestock have been shown to be an important dispersal vector. Alternatively, livestock faeces could be collected in the course of a day and used as fuel for fires, once dried, or as manure for crop fields in the near surroundings, after *P. juliflora* pods have been removed.

Flexibility of management interventions

P. juliflora control or management interventions should be context-specific, culturally sensitive and should account for the interest of both mobile pastoralism and agro-pastoralism. Clans currently affected by the *P. juliflora* invasion in proximity to the Awash River combine different livelihood strategies, including mobile pastoralism, settled small-scale agriculture and charcoal production. The reclamation and future use of land has to take note of this diversity, which should be supported. In addition, there is need to improve the provision of animal and human health care services in the Afar region to be able to handle new animal diseases like *Harmaku* and increase d incidence in malaria.

Strengthening regional cooperation and learning

In addition to local and national institutions, there is a need for regional policies and institutions to facilitate efforts to control and manage the negative impacts of *P. juliflora* and optimize the positive impacts of this species through sharing knowledge, advocacy and research. IGAD is an Eastern Africa organization created in 1996 to replace the Intergovernmental Authority on Drought and Development (IGADD) which was founded in 1986. The organization was to help member states Djibouti, Ethiopia, Kenya, Somalia, Sudan and Uganda to cope up with the recurring and severe droughts and other natural disasters between 1974 and 1984 which caused widespread famine, ecological degradation and economic hardship in the Eastern Africa region (AU 1996). The establishment of the regional institutions and policies should be spearheaded by the Intergovernmental Authority on Development (IGAD).

Encouraging further research

There is a need to invest in *P. juliflora* research in Afar in order to develop innovative ways of controlling this species but also assessing the impact of *P. juliflora* invasion in the Afar region of Ethiopia. Particular areas of research that need to be addressed are the following:

(a) The feasibility of biological control agents using experiences from other countries.
(b) The relationship between spreading patterns and hydrological conditions.
(c) The role of *P. juliflora* in desalinization and crop production.
(d) An in-depth institutional analysis to highlight why the existing *P. juliflora* management strategy for Ethiopia has not been implemented so far and what institutional arrangements will work for Prosopis management in Afar.
(e) Research on innovative uses of *P. juliflora* that are socially acceptable and suited to the Afar region and people, for example, on the possible use of *P. juliflora* pods as a source of human nutritious foods, medicinal uses and as the basis of livelihood diversification, based on the experience from other countries.

Authors' contributions

JI was leading the development of the synthesis and the economic analysis, SR was in charge of synthesizing the social analysis and ACT was in charge of synthesizing the ecological analysis. RB was the project head, and critically reviewed the results and recommendations. All authors read and approved the final manuscript.

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Competing interests

The authors declare that they have no competing interests.

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References

Adamowicz, W., J. Louviere, and M. Williams. 1994. Combining revealed and stated preference methods for valuing environmental amenities. *Journal of Environmental Economics and Management* 26: 271–292. doi:10.1006/jeem.1994.1017.

Adamowicz, W., Joffre Swait, Peter Boxall, Jordan Louviere, and Michael Williams. 1997. Perceptions vs objective measures of environmental quality in combined revealed-stated preference models of environmental valuation. *Journal of Environmental and Management* 32: 65–84.

Admasu, D. 2008. *Invasive plants and food security: The case of* Prosopis juliflora *in the Afar region of Ethiopia*, 1–13. FARM-Africa, IUCN.

ANRS. 2010. *Afar National Regional State Programme of Plan on Adaptation to Climate Change*. Environmental Protection Authority (EPA) of the Federal Democratic Republic of Ethiopia.

AU. 1996. Intergovernmental Authority for Development (IGAD). http://au.int/en/recs/igad.

Ayanu, Yohannes, Anke Jentsch, and Detlef Müller-Mahn. 2015. Ecosystem engineer unleashed: *Prosopis juliflora* threatening ecosystem services? *Regional Environmental Change* 15: 155–167. doi:10.1007/s10113-014-0616-x.

Berhanu, Abiyot, and Getachew Tesfaye. 2006. The Prosopis dilemma, impacts on dryland biodiversity and some controlling methods. *Journal of the Drylands* 1: 158–164.

Bhojvaid, P.P., and V.R. Timmer. 1998. Soil dynamics in an age sequence of *Prosopis juliflora* planted for sodic soil restoration in India. *Forest Ecology and Management* 106: 181–193. doi:10.1016/S0378-1127(97)00310-1.

Chaturvedi, Om Hari, and Artabandhu Sahoo. 2013. Nutrient utilization and rumen metabolism in sheep fed *Prosopis juliflora* pods and Cenchrus grass. *SpringerPlus* 2: 598. doi:10.1186/2193-1801-2-598.

Chekol, Wondimagegne, and Irmfried Neumann. 2014. *Prosopis juliflora*, Parthenium and beyond, challenges for an integrated strategy of IAS control in the Afar Region. In *Managing Prosopis Juliflora for better (agro-) pastoral Livelihoods in the Horn of Africa*.

Choge, S.K., N.M. Pasiecznik, M. Harvey, J. Wright, S.Z. Awan, and P.J.C. Harris. 2007. Prosopis pods as human food, with special reference to Kenya. *In Water SA* 33: 419–424. doi:10.4314/wsa.v33i3.49162.

CSA. 2014. *Ethiopia comprehensive food security and vulnerability analysis*. Addis Ababa.

Datona, Mohammed. 2014. Socio-economic impacts of *Prosopis juliflora*-related charcoal trade in Gewane Woreda, Afar Region. In *Managing Prosopis Juliflora for better (agro -) pastoral Livelihoods in the Horn of Africa*.

Earnhart, Dietrich. 2001. Combining revealed and stated preference methods to value environmental amenities at residential locations. *Land Economics* 77: 12–29. doi:http://le.uwpress.org/content/77/1/12.full.pdf+html.

Hamedu, Herrie. 2014. Socioeconomic and ecological impacts of *Prosopis juliflora* invasion in Gewane and Buremudaytu Woredas of the Afar region. In *Regional conference on managing Prosopis juliflora for better (agro-)pastoral livelihoods in the Horn of Africa*, 118–124. Addis Ababa, Ethiopia: Desalegn Hotel.

Haregeweyn, N., A. Tsunekawa, M. Tsubo, D. Meshesha, and A. Melkie. 2013. Analysis of the invasion rate, impacts and control measures of *Prosopis juliflora*: A case study of Amibara District, Eastern Ethiopia. *Environmental Monitoring and Assessment* 185: 7527–42. doi:10.1007/s10661-013-3117-3.

Hasen-Yusuf, M., A.C. Treydte, E. Abule, and J. Sauerborn. 2013. Predicting aboveground biomass of woody encroacher species in semi-arid rangelands, Ethiopia. *Journal of Arid Environments* 96: 64–72.

Ilukor, John, Regina Birner, Mesfin Tilahun, and Shimelis Getu. 2014. A social-economic assessment of the impact of *Prosopis juliflora* invasion and participative management approaches in the Afar Region, Ethiopia. In *Managing Prosopis Juliflora for better (agro-) pastoral Livelihoods in the Horn of Africa Proceedings of the Regional Conference May 1 - May 2, 2014, Addis Ababa, Ethiopia*.

Kahi, C.H., R.K. Ngugi, S.M. Mureithi, and J.C. Ng'ethe. 2009. The canopy effects of *Prosopis juliflora* (dc.) and *Acacia tortilis* (hayne) trees on herbaceous plants species and soil physico-chemical properties in Njemps flats, Kenya. *Tropical and Subtropical Agroecosystems* 1: 117–122.

Mahgoub, Osman, Isam T. Kadim, Neil E. Forsberg, Dawood S. Al-Ajmi, Naseeb M. Al-Saqry, Abdullah S. Al-Abri, and Kanthi Annamalai. 2005. Evaluation of Meskit (*Prosopis juliflora*) pods as a feed for goats. *Animal Feed Science and Technology* 121: 319–327. doi:10.1016/j.anifeedsci.2005.01.016.

Mehari, Zeraye H. 2015. The invasion of Prosopis juliflora and Afar pastoral livelihoods in the Middle Awash area of Ethiopia. Ecological Processes 4. Ecological Processes: 1–13. doi:10.1186/s13717-015-0039-8.

MoARD. 2005. *National biodiversity strategy and action plan*. Addis Ababa: Government of the federal democratic republic of Ethiopia.

Müller-Mahn, D., and S. Rettberg. 2012. *Human-environment interactions: the invasion of Prosopis juliflora in the drylands of northeast Ethiopia*. Cambridge: Changing deserts Whitehorse Press.

Mwangi, Esther, and Brent Swallow. 2008. *Prosopis juliflora* invasion and rural livelihoods in the Lake Baringo area of Kenya. *Conservation and Society* 6: 130–140.

Oba, Gufu. 2012. Harnessing pastoralists' indigenous knowledge for rangeland management: Three African case studies. *Pastoralism: Research, Policy and Practice* 2: 1. doi:10.1186/2041-7136-2-1.

Pasiecznik, P Felker, PJC Harris, LN Harsh, JC Tewari, G Cruz, K Cadoret, and LJ Maldonado. 2001. The *Prosopis juliflora - Prosopis pallida* complex: A monograph.

Rettberg, Simone. 2010. *Contested narratives of pastoral vulnerability and risk in Ethiopia' s Afar region 1*. doi:10.3362/2041-7136.2010.014.

Reuben, Ernesto. 2003. *The evolution of theories of collective action*. Amsterdan: Universidad de Amsterdam.

Ryan, Faith. 2011. *US Forest Service Technical Assistance Trip to Ethiopia: Invasive species management*. Report Submitted to USAID.

Sawal, R. K., Ram Ratan, and S. B S Yadav. 2004. Mesquite (*Prosopis juliflora*) pods as a feed resource for livestock - a review. *Asian-Australasian Journal of Animal Sciences*.

Silva, A.M., A.R. Silva, A.M. Pinheiro, S.R. Freitas, V.D. Silva, C.S. Souza, J.B. Hughes, et al. 2007. Alkaloids from *Prosopis juliflora* leaves induce glial activation, cytotoxicity and stimulate NO production. *Toxicon* 49: 601–14. doi:10.1016/j.toxicon.2006.07.037.

Stein, R B D, L R a de Toledo, F Q de Almeida, a C Arnaut, L T Patitucci, J S Neto, and V T M da Costa. 2005. Effects of feeding mesquite pod meal (*Prosopis juliflora* (Swartz) DC) for horses. *Revista Brasileira De Zootecnia-Brazilian Journal of Animal Science* 34:1240–1247.

Tilahun, Mesfin, Regina Birner, and John Ilukor. 2014. Households' demand for mitigation of *Prosopis juliflora* invasion in the Afar Region of Ethiopia: A contingent valuation. In *Managing Prosopis Juliflora for better (agro-) pastoral Livelihoods in the Horn of Africa Proceedings of the Regional Conference May 1 - May 2, 2014, Addis Ababa, Ethiopia*.

Treydte, Anna C., Emiru Birhane, and Abeje Eshete. 2014. Ecological challenges and potential carbon storage benefits of *Prosopis juliflora* in Afar. In *Managing Prosopis Juliflora for better (agro-) pastoral Livelihoods in the Horn of Africa Proceedings of the Regional Conference May 1 - May 2, 2014, Addis Ababa, Ethiopia*.

WFP. 2009. *Food security and vulnerability in selected towns of Afar and Amhara Regions, Ethiopia: WFP-Ethiopia Vulnerability Assessment and Mapping (VAM)*. Addis Ababa, Ethiopia.

Yosef, T., U. Mengistu, A. Solomon, Y.K. Mohammed, and K. Kefelegn. 2013. Camel and cattle population dynamics and livelihood diversification as a response to climate change in pastoral areas of Ethiopia. *Livestock Research for Rural Development* 25: 1–10.

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